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Takenaga et al.

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(54) **MULTICORE FIBER FOR COMMUNICATION**

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G02B 6/036 (2006.01)

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(Continued)

(58) **Field of Classification Search**
CPC G02B 6/02; G02B 6/2042
(Continued)

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Primary Examiner — Kaveh C Kianni
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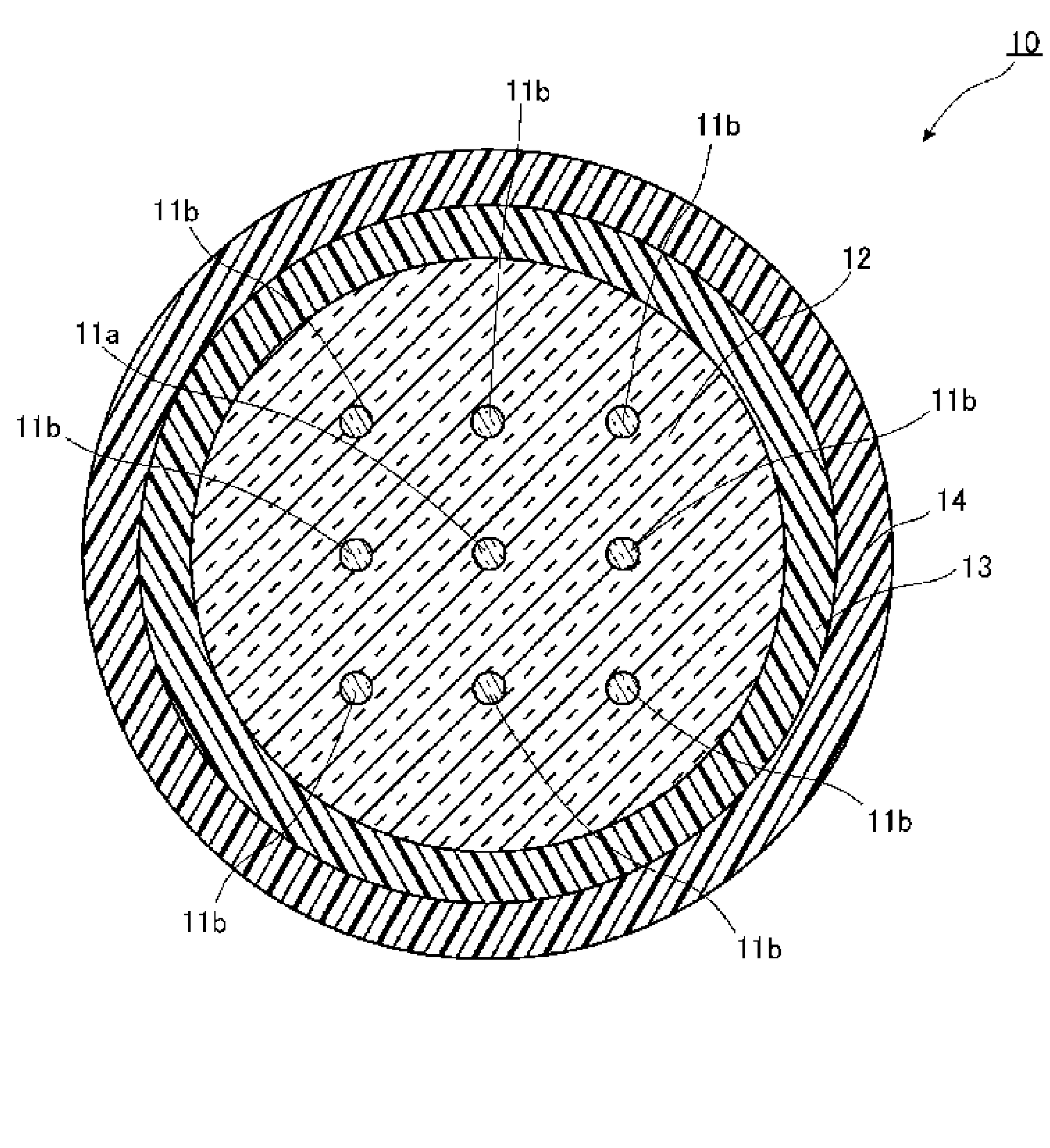
(57) **ABSTRACT**

A multicore fiber for communication **10** which allows propagation of an optical signal includes: a clad **12**; a core **11***a* which is arranged in a center of the clad **12**; and seven to ten cores **11***b* which are arranged at equal intervals surrounding the core **11***a*, and the cladding diameter is 230 μm, distances between centers of the mutually neighboring cores **11***a* and **11***b* are 30 μm or more, distances between the centers of the cores **11***b* and an outer peripheral surface of the clad **12** are 35 μm or more and a mode field diameter of light propagating in the cores **11***a* and **11***b* is 9 μm to 13 μm.

5 Claims, 7 Drawing Sheets



(52) **U.S. Cl.**
CPC ***G02B 6/02366*** (2013.01); *G02B 6/02395* (2013.01); *G02B 6/0365* (2013.01)

(58) **Field of Classification Search**
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See application file for complete search history.

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FIG. 1

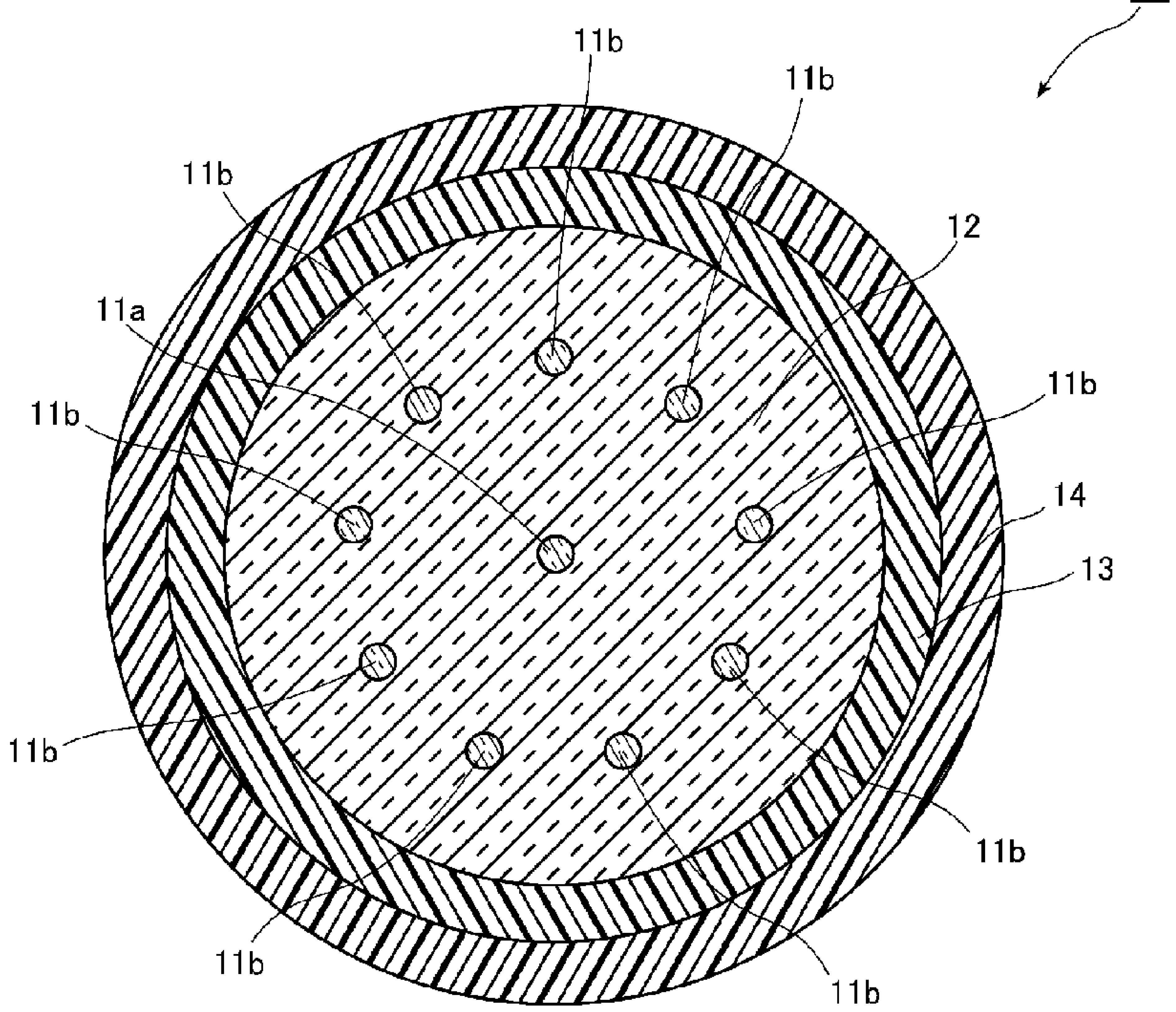

10
11b
11b
11b
12
11a
11b
11b
14
13
11b
11b
11b
11b

FIG. 2

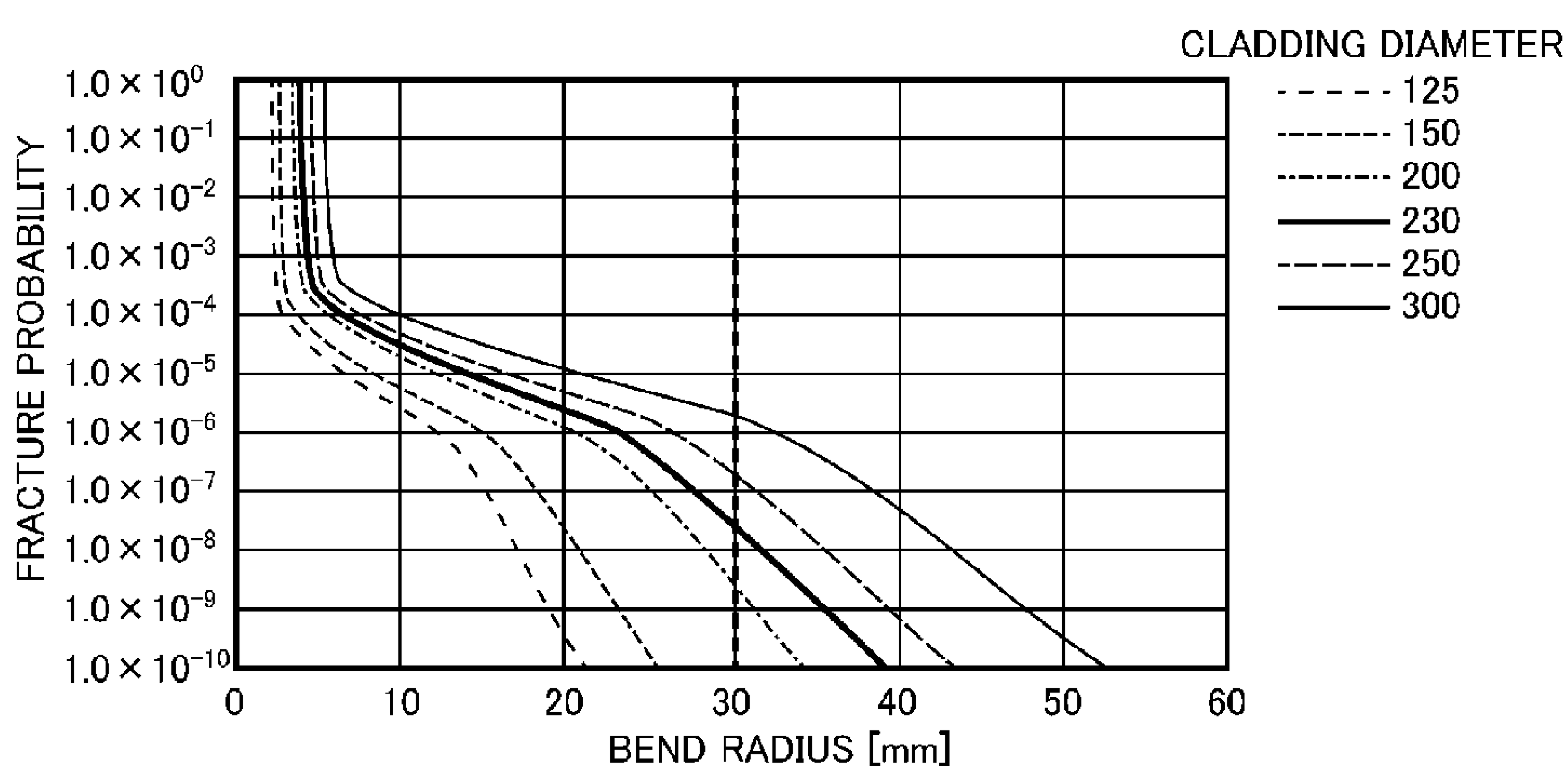

CLADDING DIAMETER
125
150
200
230
250
300
FRACTURE PROBABILITY
1.0 × 10^0
1.0 × 10^-1
1.0 × 10^-2
1.0 × 10^-3
1.0 × 10^-4
1.0 × 10^-5
1.0 × 10^-6
1.0 × 10^-7
1.0 × 10^-8
1.0 × 10^-9
1.0 × 10^-10
0
10
20
30
40
50
60
BEND RADIUS [mm]

FIG. 3

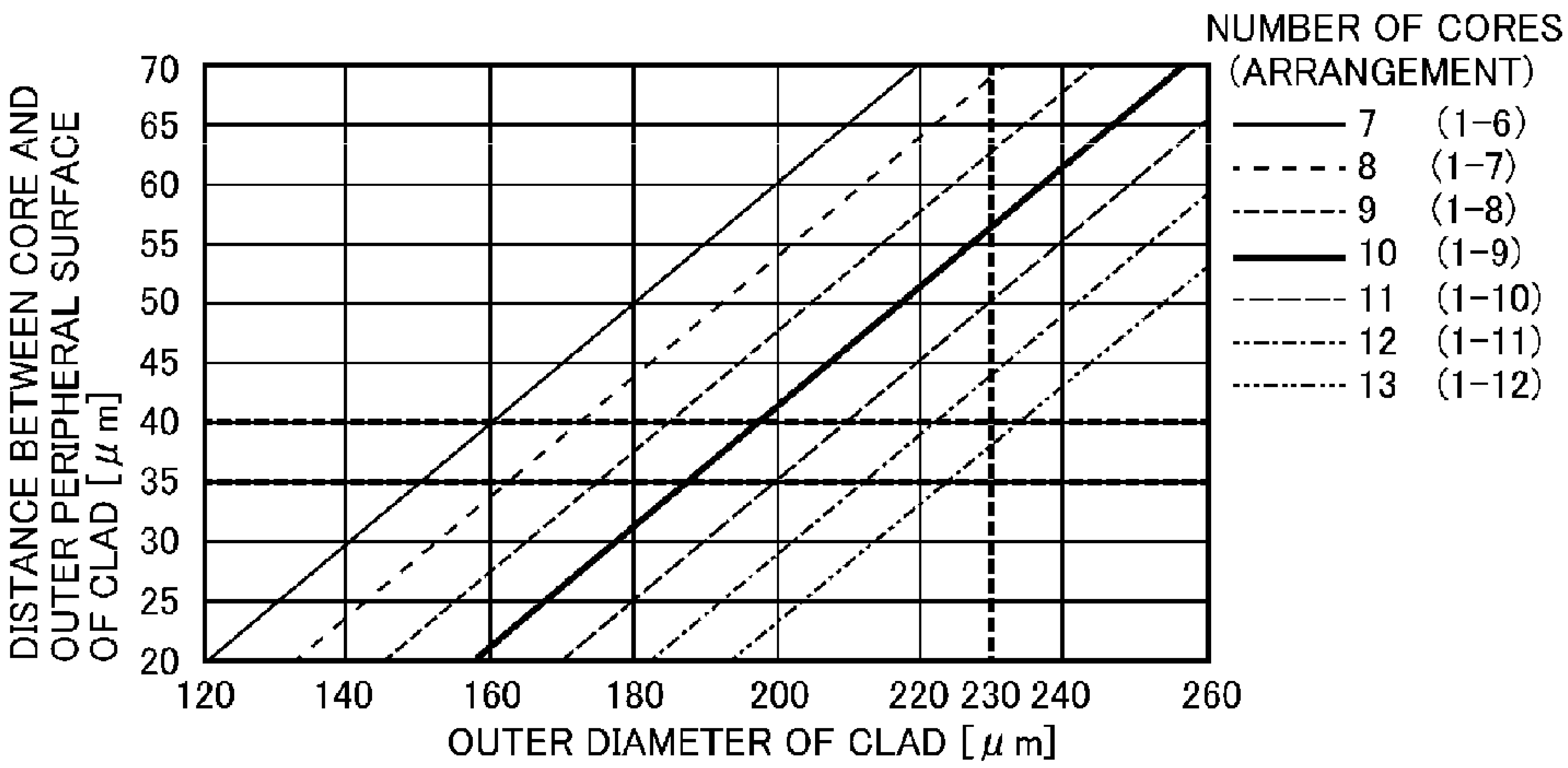

NUMBER OF CORES
(ARRANGEMENT)
7 (1-6)
8 (1-7)
9 (1-8)
10 (1-9)
11 (1-10)
12 (1-11)
13 (1-12)
DISTANCE BETWEEN CORE AND OUTER PERIPHERAL SURFACE OF CLAD [μm]
70
65
60
55
50
45
40
35
30
25
20
120
140
160
180
200
220
230
240
260
OUTER DIAMETER OF CLAD [μm]

FIG. 4

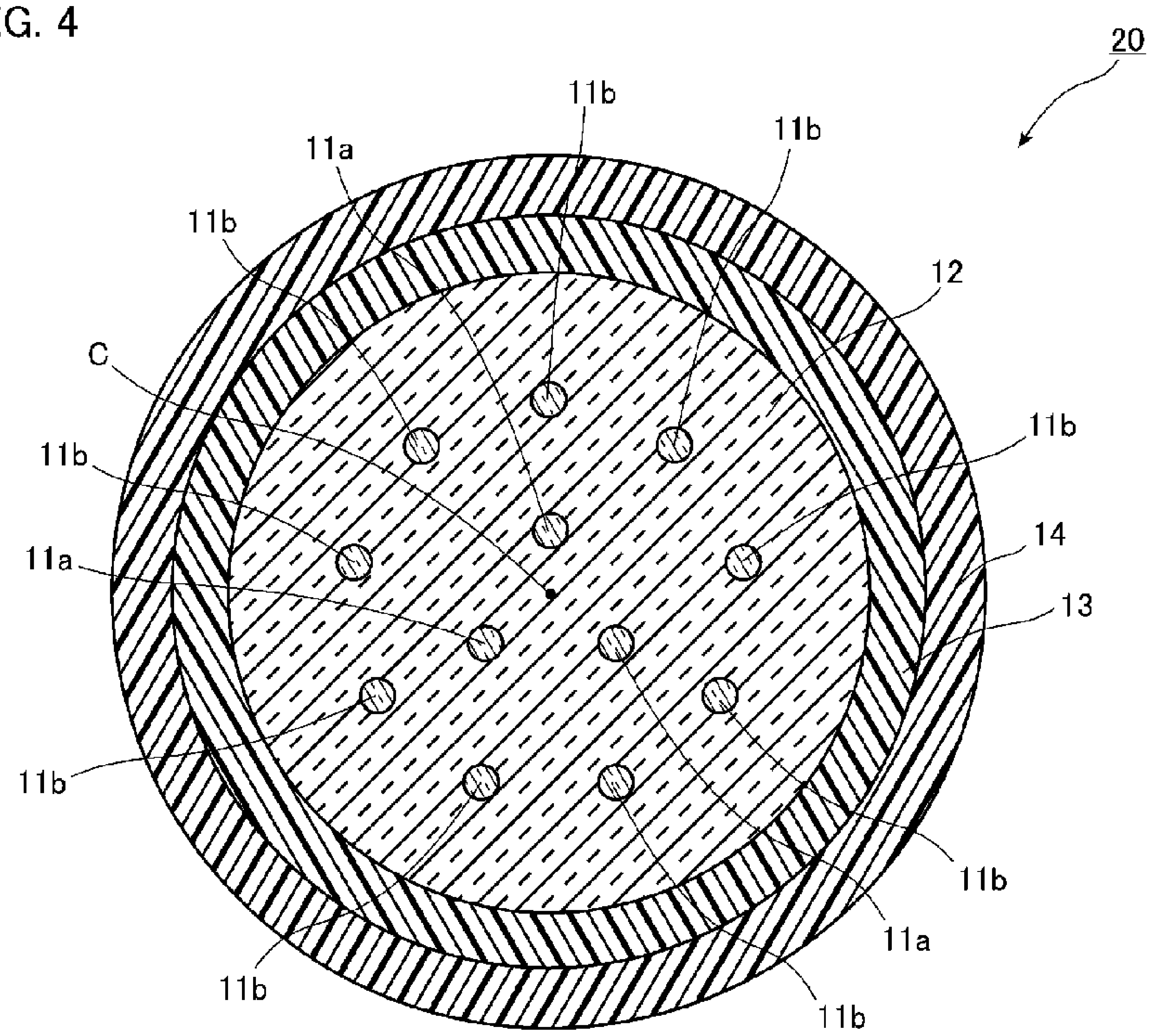

20
11b
11b
11a
11b
12
C
11b
11b
14
11a
13
11b
11b
11a
11b
11b

FIG. 5

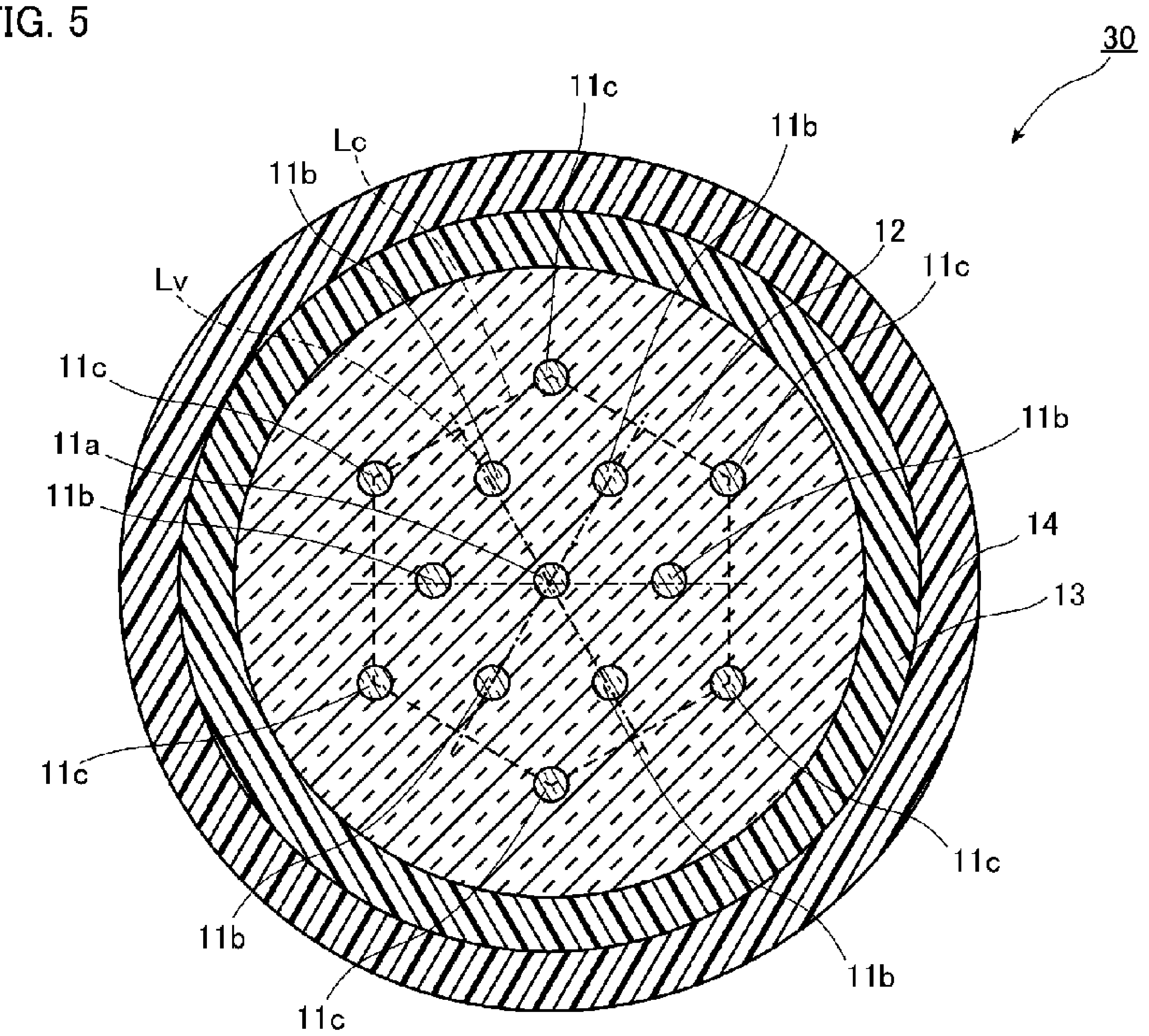

30
11c
11b
Lc
11b
12
11c
Lv
11c
11b
11a
11b
14
13
11c
11c
11b
11b
11c

FIG. 6

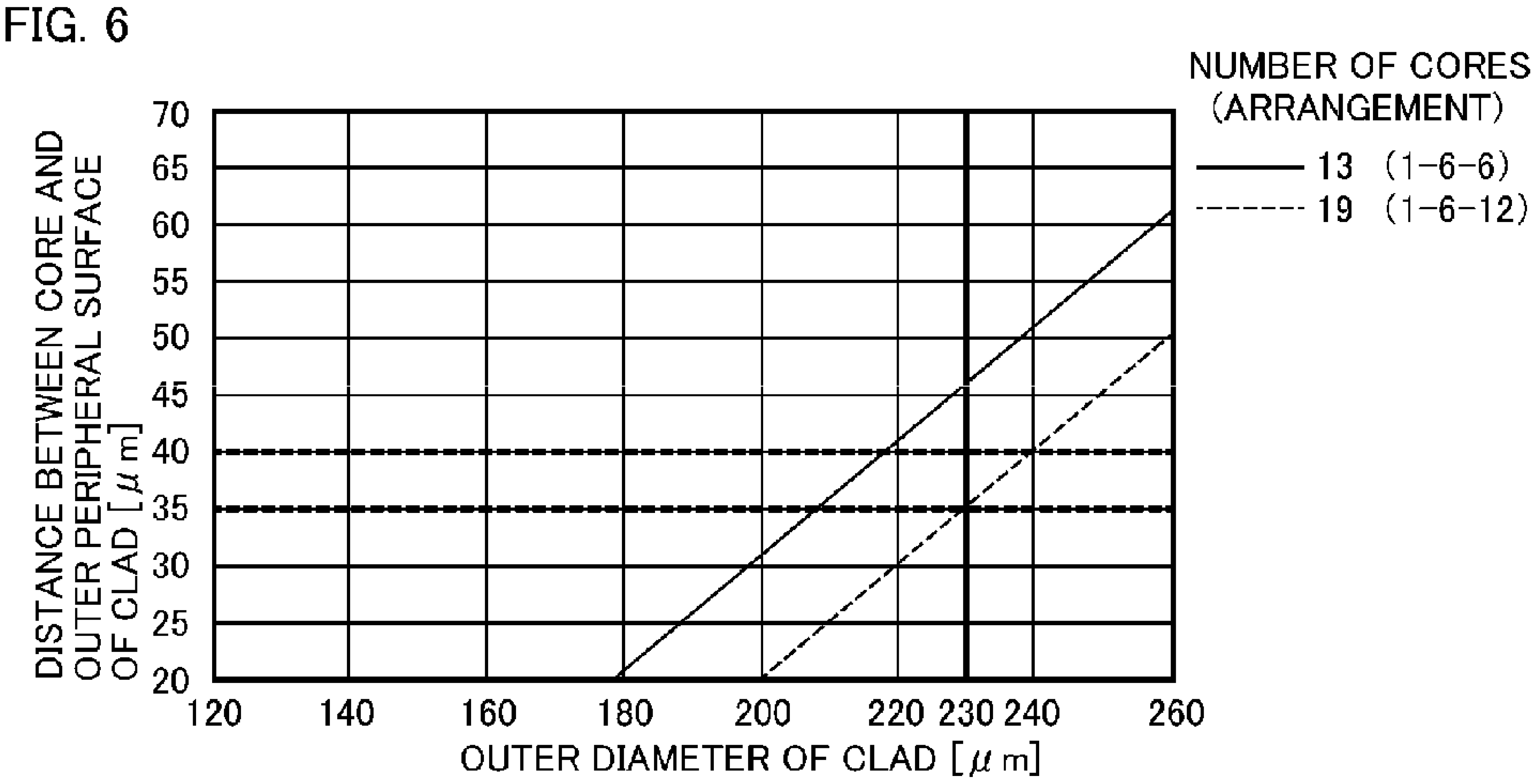

NUMBER OF CORES
(ARRANGEMENT)
13 (1-6-6)
19 (1-6-12)
DISTANCE BETWEEN CORE AND OUTER PERIPHERAL SURFACE OF CLAD [μm]
70
65
60
55
50
45
40
35
30
25
20
120
140
160
180
200
220
230
240
260
OUTER DIAMETER OF CLAD [μm]

FIG. 7

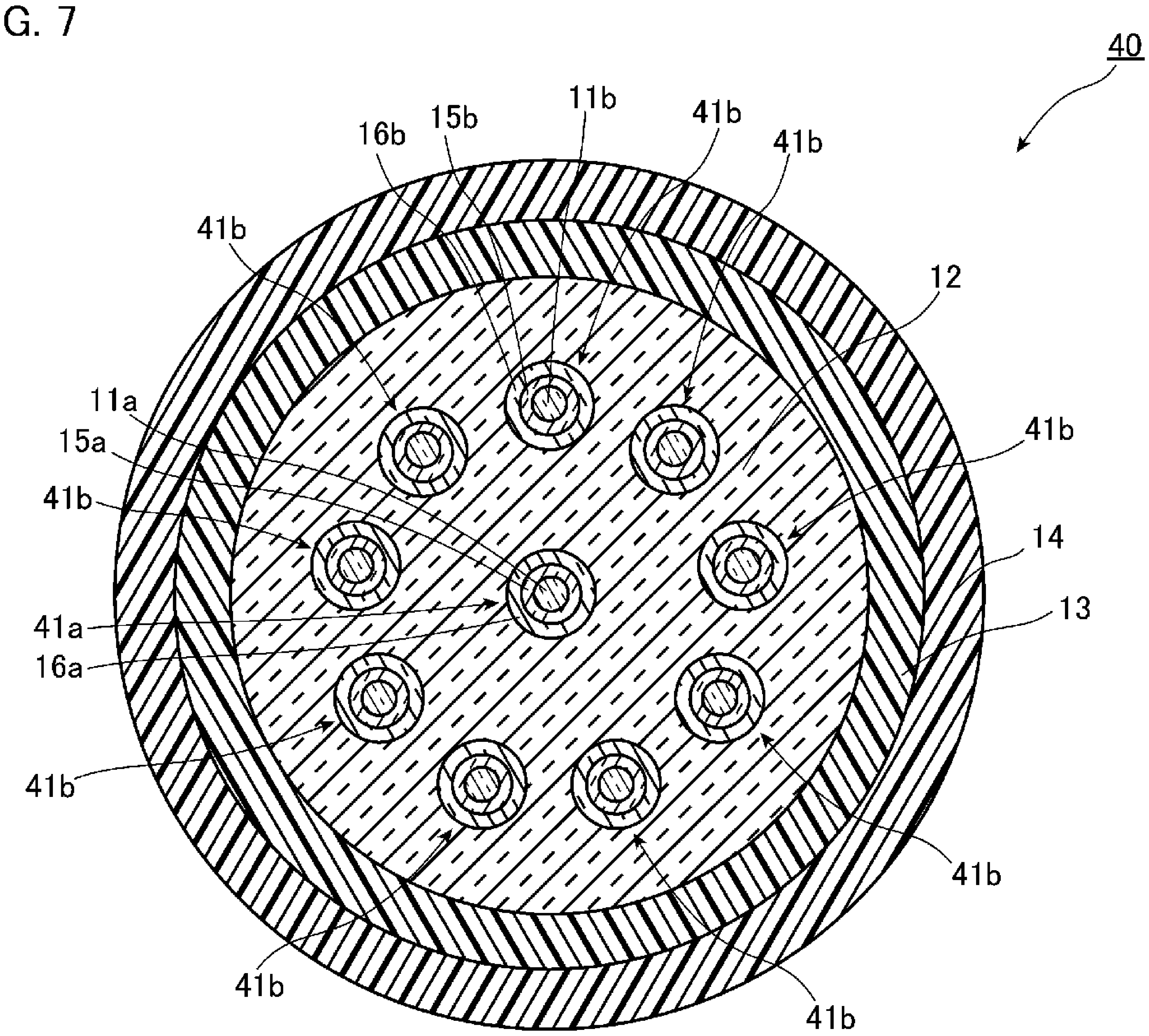

40
16b
15b
11b
41b
41b
41b
12
11a
15a
41b
41b
14
41a
16a
13
41b
41b
41b
41b

FIG. 8

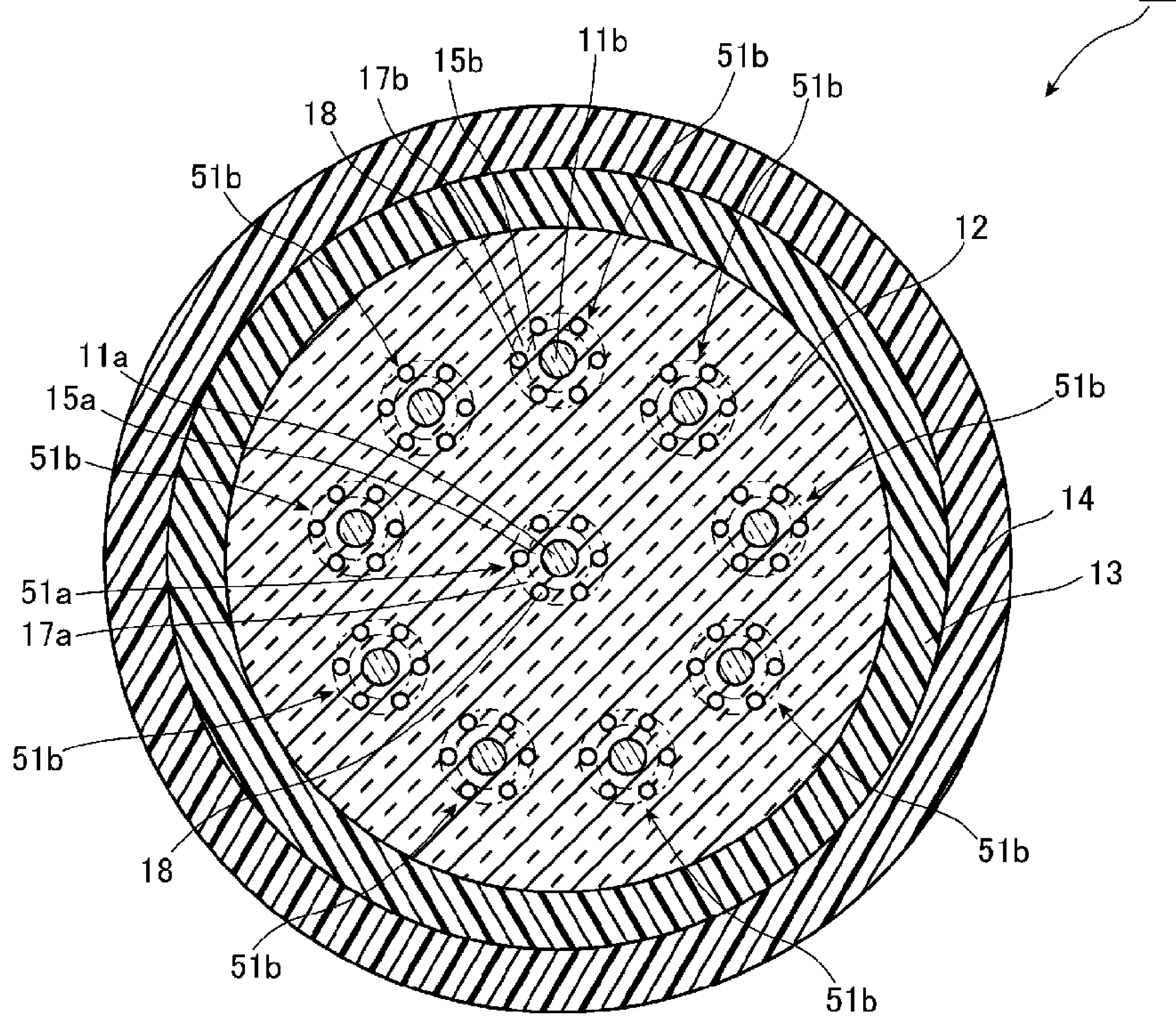

50
11b
51b
15b
51b
17b
18
51b
12
11a
15a
51b
51b
14
13
51a
17a
51b
18
51b
51b
51b

FIG. 9

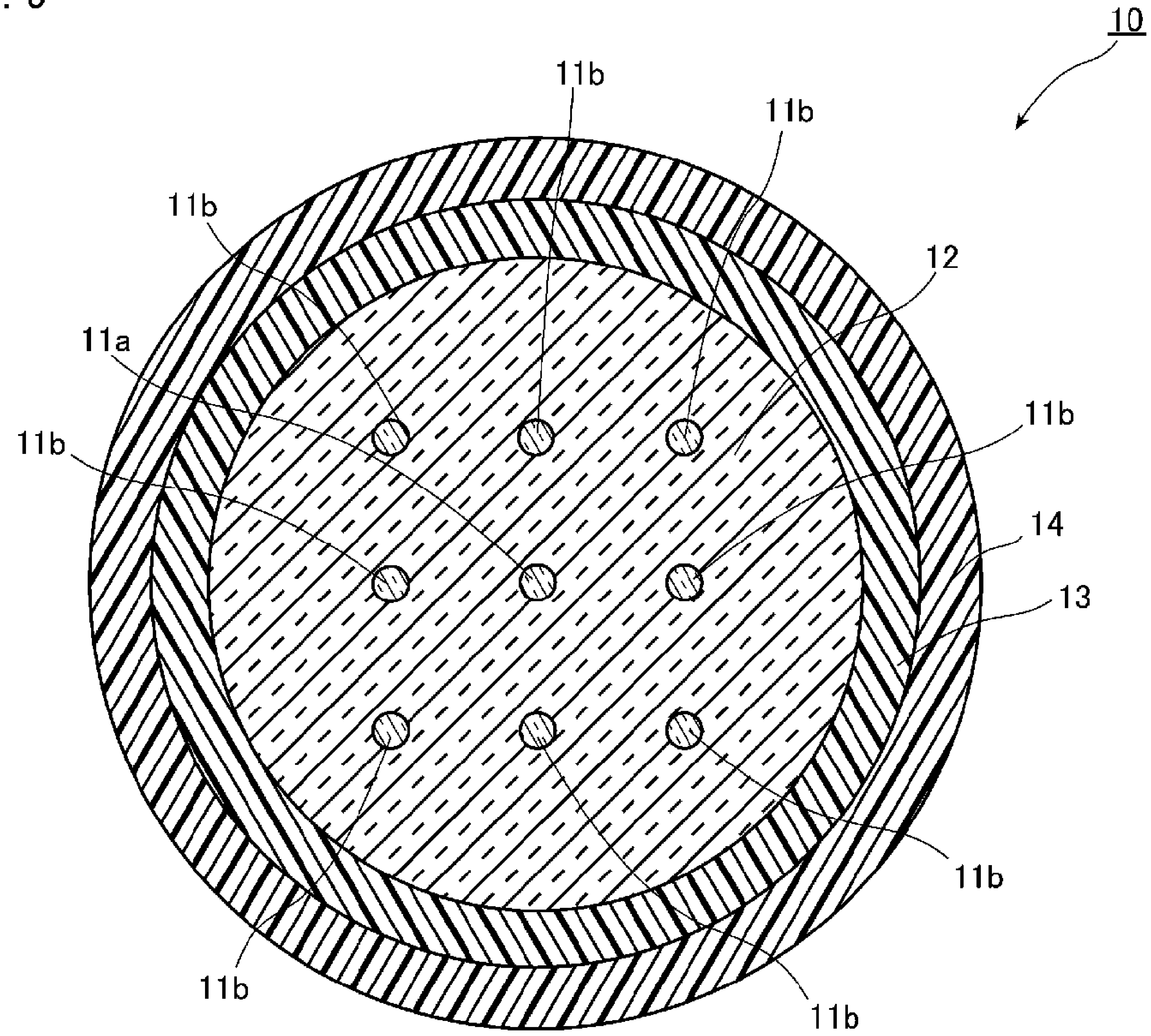
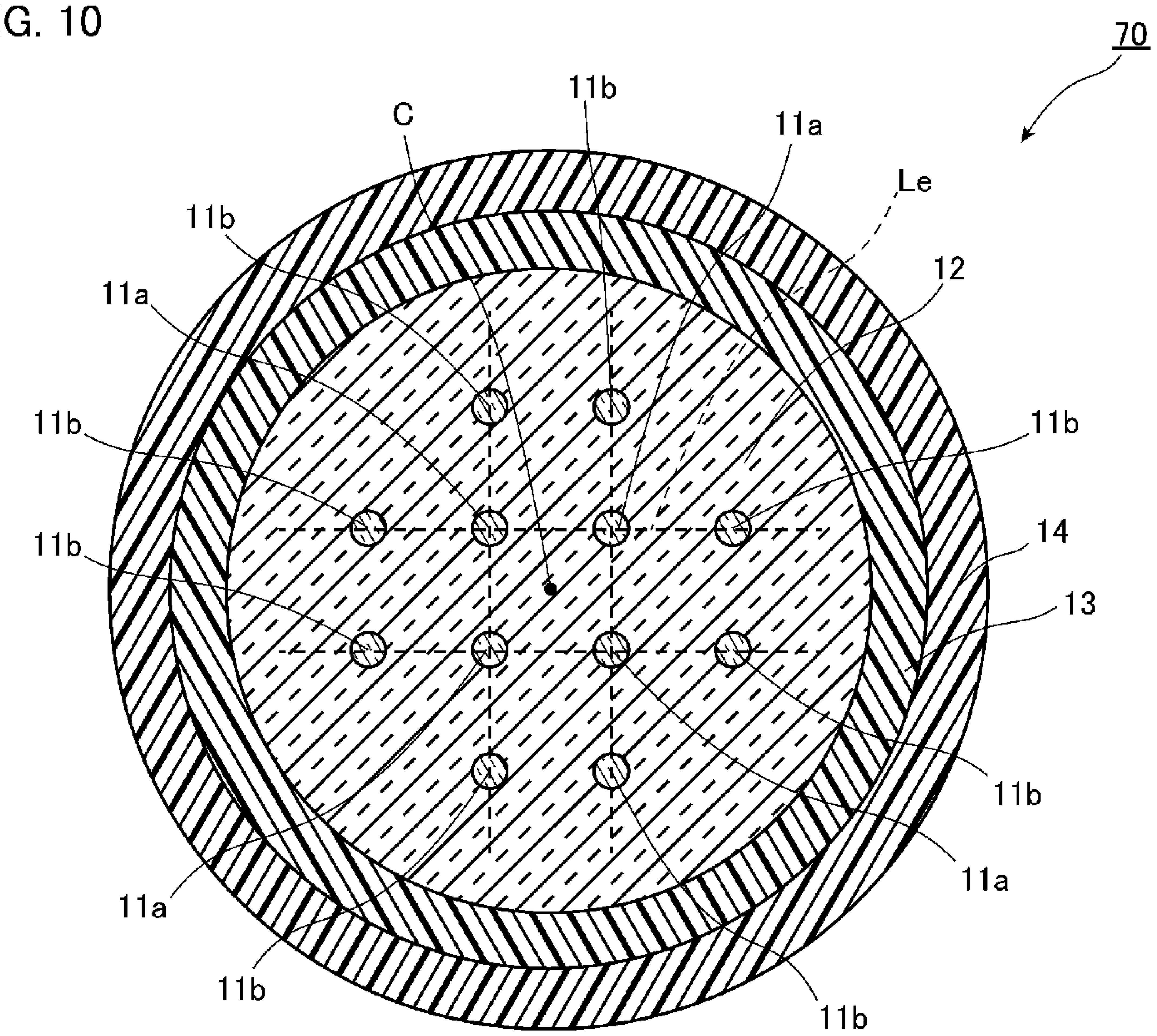


FIG. 10



MULTICORE FIBER FOR COMMUNICATION

This application is a divisional of U.S. application Ser. No. 14/194,187 filed on Feb. 28, 2014, which is based upon and claims the benefit of priority of the prior International Application No. PCT/JP2012/072510, filed on Sep. 4, 2012, and is based upon and claims the benefits of priority from Japanese Patent Application No. 2011-193403 filed on Sep. 5, 2011, the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD

The present invention relates to a multicore fiber for communication in which more cores can be arranged under conditions that the multicore fiber for communication can be laid while reliability is secured.

BACKGROUND ART

Currently, an optical fiber used for an optical fiber communication system which is generally spreading adopts a structure in which an outer periphery of a core is surrounded by a clad, and an optical signal propagates in this core to transmit information. Further, as the optical communication system spreads in recent years, the amount of information to be transmitted is remarkably increasing. As the amount of information to be transmitted increases, the optical fiber communication system uses several tens to several hundreds of multiple optical fibers to perform long distance optical communication of large capacity.

To reduce the number of optical fibers in such an optical fiber communication system, it is known as disclosed in, for example, following Non-Patent Document 1 that a plurality of signals is transmitted as light propagating in cores using a multicore fiber in which outer peripheries of a plurality of cores are surrounded by a clad.

CITATION LIST

Non Patent Document

Non-Patent Document 1: Masanori KOSHIBA "Heterogeneous multi-core fibers: proposal and design principle" IEICE Electronics Express, Vol. 6, No. 2

SUMMARY OF INVENTION

Objects to be Achieved by the Invention

In recent years, to increase the amount of information to be transmitted, a multicore fiber is demanded which has a greater number of cores than a multicore fiber which is disclosed in Non-Patent Document 1 and in which cores are provided in a 1-6 arrangement (an arrangement in which a core is arranged in the center, and six cores are arranged at equal intervals surrounding the core). As a multicore fiber which has a greater number of cores than the multicore fiber in which the cores are provided in the 1-6 arrangement, Non-Patent Document 1 discloses a multicore fiber in which cores are provided in a 1-6-12 arrangement (an arrangement in which a core is arranged in the center, six cores are arranged at equal intervals surrounding this core, and twelve cores are further arranged at equal intervals surrounding these six cores). However, the multicore fiber in which the cores are provided in the 1-6-12 arrangement has a concern that distances between the outer peripheral surface of the clad and the cores are too close and, in this case, microbend loss is likely to occur, and therefore reliability of the multicore fiber decreases.

Hence, distances between cores may be increased by increasing a cladding diameter of a multicore fiber. However, when the cladding diameter is increased too much, if the multicore fiber is bent and laid, the multicore fiber is easily fractured and reliability decreases in some cases.

It is therefore an object of the present invention to provide a multicore fiber for communication in which more cores can be arranged under conditions that the multicore fiber for communication can be laid while reliability is secured.

Means for Achieving the Objects

Conventionally, an allowable minimum bend radius of an optical fiber for transmitting an optical signal is 30 mm or more from the view point of bend loss characteristics. Meanwhile, in recent years, a fiber is being developed which causes little loss of light (bend loss) due to a bend, causes no bend loss even when the bend radius is 15 mm or less and is durable against a bend. However, it is known that, if a long period of time passes in a state where a portion having a small diameter is bent, the optical fiber is fractured due to a slight scratch in silica glass. Hence, the minimum bend radius which an optical fiber which is durable against a bend requires is determined prioritizing conditions based on a view point of reliability over conditions based on a view point of bend loss. Further, as an index for securing reliability of an optical fiber which is durable against a bend, an optical fiber in which a cladding diameter is 125 μm requires a condition that the bend radius be less than 30 mm, and a fracture probability in twenty years is preferably 1.0×10^{-7} or less in a state where the bend radius is 15 mm and the number of winding is 100. Meanwhile, a screening level of an optical fiber assumes an elongation strain of 1%. Hence, for an optical fiber in which an cladding diameter is 125 μm or more, the bend radius which is conventionally employed is used and the above condition that the number of winding is 100 which is the condition of the optical fiber in which the cladding diameter is 125 μm is used, and, as long as the fracture probability in twenty years is 1.0×10^{-7} or less in a state where the bend radius is 30 mm and the number of winding is 100, it is possible to secure sufficient reliability for a communication optical fiber. Further, the inventors of the present invention found that the cladding diameter needs to be 230 μm or less to satisfy the condition that the fracture probability in twenty years is 1.0×10^{-7} or less in the state where the bend radius is 30 mm and the number of winding is 100. Hence, the inventors of the present invention made diligent study to arrange more cores in a clad which has such an outer shape, and made the present invention.

That is, an aspect of the present invention includes: a clad; a core which is arranged in a center of the clad; and seven to twelve cores which are each arranged at equal distances from the center and at equal intervals surrounding the core, and an cladding diameter is 230 μm or less.

According to this multicore fiber for communication, the cladding diameter is 230 μm or less, so that it is possible to secure reliability for fracture caused when the multicore fiber for communication is laid. Compared to an optical fiber in which cores are provided in a 1-6-12 arrangement, it is possible to increase distances between outermost periphery side cores and an outer peripheral surface of the clad when the distances between cores are the same as those of this multicore fiber. Consequently, it is possible to suppress microbend loss, and secure reliability.

Further, while, in a multicore fiber in which cores are provided in a 1-6 arrangement, a core which is arranged in the center and two mutually neighboring cores which are arranged on an outer side form a regular triangle, the present invention has seven or more the outer periphery side cores, so that the core which is arranged in the center and two mutually neighboring cores are arranged on the outer side form an isosceles triangle. Hence, distances between centers of the center core and the outer periphery side cores are greater than the distances between the centers of the mutually neighboring outer periphery side cores. When the distances between the cores increase, crosstalk decreases, and crosstalk between the center core and the outer periphery side cores is less than crosstalk between the outer periphery side cores. Hence, when optical signals enter all cores, although a center core having a greater number of the closest cores includes a greater total sum of crosstalk, it is possible to suppress a total sum of crosstalk of the center core according to the relationship.

Further, even though such a multicore fiber for communication can transmit optical signals in this way without deteriorating the optical signals, eight or more cores are arranged therein, so that it is possible to arrange more cores and transmit a greater amount of information than a conventional common multicore fiber in which cores are provided in the 1-6 arrangement.

Furthermore, another aspect of the present invention includes: a clad; three cores which are each arranged at equal distances from a center of the clad and at equal intervals; and five to twelve cores which are each arranged at equal distances from the center and at equal intervals surrounding the core, and an cladding diameter is 230 μm or less.

Eight or more cores are also arranged according to such a core arrangement, so that it is possible to arrange more cores and transmit a greater amount of information than a conventional common multicore fiber in which cores are provided in the 1-6 arrangement. Further, compared to the multicore fiber in which the cores are provided in the 1-6-12 arrangement, it is possible to suppress microbend loss more and secure reliability when the distances between the cores are the same as those of this multicore fiber.

Furthermore, still another aspect of the present invention is a multicore fiber for communication which allows propagation of an optical signal, and includes: a clad; a core which is arranged in a center of the clad; and six cores which are each arranged at equal distances from the center and at equal intervals surrounding the core; and one to six cores which are arranged between a connection line which connects two mutually neighboring cores of the six cores and the core, and on the line which is vertical to the connection line and passes on the core, and an cladding diameter is 230 μm or less.

According to such a multicore fiber for communication, the cores are arranged in three layers, and one to six cores are arranged in the second layer. That is, the cores are arranged in a 1-6-6 arrangement from the 1-1-6 arrangement. Consequently, eight to thirteen cores are arranged as a whole, so that it is possible to arrange more cores and transmit a greater amount of information than the conventional common multicore fiber in which cores are provided in a 1-6 arrangement. Further, compared to the multicore fiber in which the cores are provided in the 1-6-12 arrangement, it is possible to suppress microbend loss more and secure reliability when the distances between the cores are the same as those of this multicore fiber.

Furthermore, another aspect of the present invention includes: a clad; a core which is arranged in a center of the clad; and eight cores which surround the core and are arranged at equal intervals to form a square shape as a whole, and an cladding diameter is 230 μm or less.

According to such a core arrangement, it is also possible to arrange more cores and transmit a greater amount of information than a conventional common multicore fiber in which cores are provided in the 1-6 arrangement. Further, compared to the multicore fiber in which the cores are provided in the 1-6-12 arrangement, it is possible to suppress microbend loss more and secure reliability when the distances between the cores are the same as those of this multicore fiber.

Furthermore, still another aspect of the present invention includes: a clad; four cores which are each arranged at equal distances from a center of the clad and at equal intervals; and eight cores which are arranged on an extended line which connects two mutually neighboring cores of the four cores, and which are arranged such that distances to a center of a closest core of the four cores are equal to distances between centers of the two mutually neighboring cores of the four cores, and an cladding diameter is 230 μm or less.

According to such a core arrangement, it is also possible to arrange more cores and transmit a greater amount of information than a conventional common multicore fiber in which cores are provided in the 1-6 arrangement. Further, compared to the multicore fiber in which the cores are provided in the 1-6-12 arrangement, it is possible to suppress microbend loss more and secure reliability when the distances between the cores are the same as those of this multicore fiber.

Furthermore, in any one of the invention, a mode field diameter of light propagating in each of the cores is 9 μm to 13 μm, and a distance between centers of the cores which are mutually neighboring is 30 μm or more, and a distance between the center of the core and an outer peripheral surface of the clad is preferably 35 μm or more.

When information is transmitted using the multicore fiber, the mode field diameter is about 9 μm to 13 μm, so that it is possible to suppress loss of an optical signal. This is because the mode field diameter is 9 μm or more, so that it is possible to prevent loss of light from increasing due to a non-linear optical effect because of concentration of light on cores, and the mode field diameter is 13 μm or less, so that it is possible to prevent loss of light from increasing due to an increase of the amount of light leaking to an outside of the cores. Further, the mode field diameter is to 9 μm to 13 μm and the distance between the centers of the mutually neighboring cores is 30 μm or more, so that it is possible to suppress crosstalk. Furthermore, the mode field diameter is 9 μm to 13 μm and the distance between the center of the core and the outer peripheral surface of the clad is 35 μm or more, so that it is possible to prevent loss of an optical signal due to absorption of light in a protective layer which covers the clad.

Still further, the invention preferably includes: an inner clad layer which has a lower refractive index than that of the core and which surrounds the core; and a low refractive index layer which has a lower average refractive index than those of the clad and the inner clad layer and which surrounds the inner clad layer. Each low refractive index layer surrounds each core across the inner clad layer, so that an effect of light confinement in each core is great and light hardly leaks from the cores. Consequently, it is possible to reduce crosstalk between the cores.

Further, in the invention, the low refractive index layer is made of a material having a lower refractive index than those of the clad and the inner clad layer. As to the refractive index of such a low refractive index layer, when each core element is viewed from the view point of the refractive index, the low refractive index layer has a trench shape which is referred to a "trench structure". Such a structure is adopted, so that it is possible to suppress loss resulting from a bend of a fiber more, and a manufacturing method for mass production has already been established, so that it is possible to easily manufacture multicore fibers for communication at low cost.

Alternatively, in the above invention, in the low refractive index layer, a plurality of low refractive index portions which has lower refractive indices than those of the clad and the inner clad layer is formed to surround the inner clad layer. In such a low refractive index layer, the low refractive index portions are not continuously formed annularly to surround the cores, so that it is possible to prevent each core from intensifying confinement of a higher mode, and prevent a cutoff wavelength of each core from becoming longer.

Further, the low refractive index portion may be a hole. In this case, it is possible to make the refractive index of the low refractive index layer lower, and further reduce crosstalk while preventing each core from intensifying confinement of a higher mode.

Effect of Invention

As described above, the present invention provides a multicore fiber for communication in which more cores can be arranged under conditions that the multicore fiber for communication can be laid while reliability is secured.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a view illustrating a structure of a vertical cross section of a multicore fiber for communication in a longitudinal direction according to a first embodiment of the present invention.

FIG. **2** is a view illustrating a relationship between the bend radius and the failure probability of an optical fiber.

FIG. **3** is a view illustrating a relationship between an cladding diameter and distances between outer periphery side cores and an outer peripheral surface of the clad when one core is arranged in the center and a plurality of cores is arranged around this core.

FIG. **4** is a view illustrating a structure of a vertical cross section of a multicore fiber for communication in a longitudinal direction according to a second embodiment of the present invention.

FIG. **5** is a view illustrating a structure of a vertical cross section of a multicore fiber for communication in a longitudinal direction according to a third embodiment of the present invention.

FIG. **6** is a view illustrating a relationship between an cladding diameter and distances between outer periphery side cores and an outer peripheral surface of the clad when one core is arranged in the center, six cores are arranged around this core and a plurality of cores is arranged around these six cores at equal intervals.

FIG. **7** is a view illustrating a structure of a vertical cross section of a multicore fiber for communication in a longitudinal direction according to a fourth embodiment of the present invention.

FIG. **8** is a view illustrating a structure of a vertical cross section of a multicore fiber for communication in a longitudinal direction according to a fifth embodiment of the present invention.

FIG. **9** is a view illustrating a structure of a vertical cross section of a multicore fiber for communication in a longitudinal direction according to a six embodiment of the present invention.

FIG. **10** is a view illustrating a structure of a vertical cross section of a multicore fiber for communication in a longitudinal direction according to a seventh embodiment of the present invention.

DESCRIPTION OF EMBODIMENTS

Suitable embodiments of a multicore fiber for communication (referred to as a "multicore fiber" below) according to the present invention will be explained in detail hereinafter referring to the drawings.

(First Embodiment)

FIG. **1** is a view illustrating a structure of a vertical cross section of a multicore fiber in a longitudinal direction according to a first embodiment of the present invention. As illustrated in FIG. **1**, a multicore fiber **10** according to the present embodiment has a clad **12**, a core **11***a* which is arranged in the center in a cross section of the clad **12**, nine cores **11***b* which are arranged at equal intervals surrounding the core **11***a*, an inner protective layer **13** which covers an outer peripheral surface of the clad **12** and an outer protective layer **14** which covers an outer peripheral surface of the inner protective layer **13**. That is, in the multicore fiber **10** according to the present embodiment, a plurality of cores **11***a* and **11***b* is provided in a 1-9 arrangement.

This multicore fiber **10** is an optical fiber which allows propagation of an optical signal, and a mode field diameter of light propagating in the cores **11***a* and **11***b* is preferably 9 μm to 13 μm. The mode field diameter is 9 μm or more, so that it is possible to prevent loss of light from increasing due to a non-linear optical effect because of concentration of light on cores, and the mode field diameter is 13 μm or less, so that it is possible to prevent loss of light from increasing due to an increase of the amount of light leaking to an outside of the cores.

The clad **12** has a virtually circular shape as an outer shape in the cross section, and surrounds the outer peripheral surfaces of a plurality of cores **11***a* and **11***b* without gaps. A material for forming the clad **12** is not limited in particular as long as the material is generally used for a clad, and the material is made of, for example, pure silica glass doped without a dopant.

The respective cores **11***a* and **11***b* are preferably arranged such that distances between centers of the mutually neighboring cores **11***a* and **11***b* are 30 μm or more and, more preferably, 40 μm or more. The cores **11***a* and **11***b* are arranged in this way, so that it is possible to suppress crosstalk between the mutually neighboring cores **11***a* and **11***b*. Particularly when the mode field diameter is 9 to 13 μm as described above, it is possible to prevent crosstalk by arranging the cores **11***a* and **11***b* in this way. Further, the cores **11***b* arranged on the outer periphery side are preferably arranged such that distances between the centers of the cores **11***b* and the outer peripheral surface of the clad **12** are 35 μm or more and, more particularly, 40 μm or more. The cores **11***b* are arranged on the outer periphery side in this way, so that it is possible to prevent loss of an optical signal caused when light propagating in the core **11***b* on the outer periphery side is absorbed by the inner protective layer **13**.

Further, the respective cores **11**b arranged on the outer periphery side are arranged at equal distances from the center of the clad **12** and at equal intervals. The cores **11**a and **11**b arranged in this way are symmetrical with respect to a center axis of the clad **12**. That is, when the multicore fiber **10** is rotated around the center axis of the clad **12** at a predetermined angle, positions of the outer periphery side cores **11**b after rotation come to positions of the other outer periphery side cores **11**b before rotation. Further, the core **11**a arranged in the center does not move even when the multicore fiber **10** is rotated about the center axis. The respective cores **11**a and **11**b are arranged at positions symmetrical with respect to the center axis of the clad **12** in this way, so that it is possible to make an optical property resulting from the arrangement of the cores **11**a and **11**b uniform.

Further, the distances between the centers of the center core **11**a and the outer side cores **11**b are made longer than the distances between the centers of the mutually neighboring outer side cores **11**b to draw an isosceles triangle with the core **11**a and the two mutually neighboring cores **11**b arranged in this way.

Furthermore, the diameters of the respective cores **11**a and **11**b are not limited in particular and, for example, 8.7 μm to 12 μm. In addition, the diameters of the mutually neighboring cores **11**a and **11**b are preferably slight different from each other. In this case, for example, the diameters of the cores **11**b arranged on the outer periphery side are about 3% different from the diameter of the core **11**a arranged in the center, and the diameters of the mutually neighboring cores **11**b arranged on the outer periphery side are about 0.5% to 5% different from each other. Thus, although, even when the diameters of the mutually neighboring cores **11**a and **11**b are physically slightly different, the cores **11**a and **11**b have only slightly different diameters for light propagating in the cores **11**a and **11**b and have the substantially same optical characteristics, the diameters of the mutually neighboring cores **11**a and **11**b are physically slightly different, so that it is possible to prevent crosstalk between the mutually neighboring cores **11**a and **11**b.

Further, the refractive indices of the cores **11**a and **11**b are higher than the refractive index of the clad **12**, and a relative refractive index difference Δ with respect to the clad of the respective cores **11**a and **11**b is not limited in particular and is, for example, 0.21% to 0.5%.

In addition, the refractive indices of mutually neighboring cores of the respective cores **11**a and **11**b are preferably different from each other from the view point of preventing crosstalk between the respective cores **11**a and **11**b. In this case, the differences between the refractive indices of the mutually neighboring cores **11**a and **11**b are preferably 1% to 5% of the refractive indices from the view point of preventing crosstalk and making optical characteristics of the cores equal.

A material of these cores **11**a and **11**b is not limited in particular as long as the material has the refractive index which is higher than the clad **12** and is the above relative refractive index difference with respect to the clad, and is, for example, silica glass doped with a dopant such as germanium which increases the refractive index.

Further, a material of the inner protective layer **13** and the outer protective layer **14** includes ultraviolet curable resin of different types from each other.

In addition, this multicore fiber **10** can be manufactured by a stack and draw method. That is, a plurality of rod-shaped core glass members which form the cores **11**a and **11**b, a tubular clad glass member which forms part of the clad **12** and a rod-shaped clad glass member which forms part of the clad **12** are prepared first. Further, the respective core glass members are arranged in penetration holes of the tubular clad glass member, and the rod-shaped clad glass member is arranged between the tubular clad glass member and the core glass members to fill gaps. Furthermore, these members are collapsed in a state where the core glass members are arranged to make a fiber base material in which an arrangement in the cross section has a similar figure without the inner protective layer **13** and the outer protective layer **14** in the multicore fiber **10** illustrated in FIG. **1**. Still further, the created fiber base material is heated, melted and spun to make a multicore fiber, and this multicore fiber is covered by the inner protective layer **13** and the outer protective layer **14** to make the multicore fiber **10**. Alternatively, the core glass members and the rod-shaped clad glass member may be spun while being collapsed in a state where the core glass members and the rod-shaped clad glass member are arranged in penetration holes of the tubular clad glass member.

Alternatively, in an intermediate base material which has in the center the core glass member which forms the core **11**a, penetration holes are made around the core glass member which is the center of the clad glass member, glass rods which have the core glass members are inserted in these penetration holes, and the these glass rods and the clad glass members are collapsed filling the gaps therebetween to make the same fiber base material as the above. Further, the members are spun in the same way as the above and covered by the inner protective layer **13** and the outer protective layer **14** to make the multicore fiber **10**. Alternatively, the members may be spun while being collapsed in a state where the above glass rods are inserted in the above penetration holes.

Next, the cladding diameter will be described. Conventionally, an allowable minimum bend radius of an optical fiber for transmitting an optical signal is 30 mm or more from the view point of bend loss characteristics. Meanwhile, in recent years, a fiber is being developed which causes little loss of light (bend loss) due to a bend, causes no bend loss even when the bend radius is 15 mm or less and is durable against a bend. However, it is known that, if a long period of time passes in a state where a portion having a small diameter is bent, the optical fiber is fractured due to a slight scratch in silica glass. Hence, the minimum bend radius which an optical fiber requires is determined prioritizing conditions based on a view point of reliability over conditions based on a view point of bend loss. Further, as an index for securing reliability, an optical fiber in which an cladding diameter is 125 μm requires a condition that the bend radius be less than 30 mm, and a fracture probability in twenty years is preferably 1.0×10^{-7} or less in a state where the bend radius is 15 mm and the number of winding is 100. Meanwhile, a screening level of an optical fiber assumes an elongation strain of 1%. Hence, for an optical fiber in which an cladding diameter is 125 μm or more, the bend radius which is conventionally employed is used and the above condition that the number of winding is 100 which is the condition of the optical fiber in which the cladding diameter is 125 μm is used, and, as long as the fracture probability in twenty years is 1.0×10^{-7} or less in a state where the bend radius is 30 mm and the number of winding is 100, it is possible to secure sufficient reliability for a communication optical fiber.

FIG. **2** is a view illustrating a relationship between the bend radius and the fracture probability of an optical fiber. FIG. **2** illustrates curves illustrating relationships between bend radii and fracture probabilities in twenty years when optical fibers in which cladding diameters are 125 μm, 150 μm, 200 μm, 230 μm, 250 μm and 300 μm are wound a hundred times.

As illustrated in FIG. **2**, when the diameter is 230 μm or less, the fracture probability in the twenty years in case that the optical fiber is wound a hundred times is 1.0×10^{-7} or less. Hence, to lay the multicore fiber while reliability is secured, the cladding diameter of the multicore fiber **10** is 230 μm or less. Further, when the distances between the centers of the mutually neighboring ores **11***a* and **11***b* are 30 μm or more and the distances between the centers of the cores **11***b* arranged on the outer periphery side and the outer peripheral surface of the clad **12** are 35 μm or more, the cladding diameter is 158 μm to 230 μm in the multicore fiber **10** in which the cores are provided in a 1-9 arrangement as in the present embodiment. Furthermore, when the distances between the centers of the mutually neighboring cores **11***a* and **11***b* are 40 μm or more and the distances between the centers of the cores **11***b* arranged on the outer periphery side and the outer peripheral surface of the clad **12** are 40 μm or more, the cladding diameter is 197 μm to 230 μm in the multicore fiber **10** in which the cores are provided in a 1-9 arrangement as in the present embodiment.

As described above, according to this multicore fiber **10**, the cladding diameter is 230 μm or less, so that it is possible to secure reliability for fracture caused when the multicore fiber **10** is laid. Further, compared to an optical fiber in which cores are provided in a 1-6-12 arrangement, it is possible to increase distances between the centers of the outermost periphery side cores **11***b* and an outer peripheral surface of the clad **12** when the distances between cores are the same as those of this multicore fiber. Consequently, it is possible to suppress microbend loss, and secure reliability.

Further, the multicore fiber **10** has reliability as described above and has 10 cores arranged therein, and, consequently, can transmit a greater amount of information than a conventional common multicore fiber in which cores are provided in a 1-6 arrangement.

Furthermore, while, in a multicore fiber in which cores are provided in the 1-6 arrangement, a core which is arranged in the center and two mutually neighboring cores which are arranged on an outer side form a regular triangle, the multicore fiber **10** according to the present invention has seven or more outer periphery side cores **11***b*, so that the core **11***a* arranged in the center and two mutually neighboring cores arranged on the outer side form an isosceles triangle. Hence, distances between the centers of the center core **11***a* and the outer periphery side cores **11***b* are greater than the distances between the centers of the mutually neighboring outer periphery side cores **11***b*. When the distances between the cores increase, crosstalk decreases, and crosstalk between the center core **11***a* and the outer periphery side cores **11***b* is less than crosstalk between the outer periphery side cores **11***b*. Hence, when optical signals enter all cores **11***a* and **11***b*, although the center core **11***a* having a greater number of the closest cores includes a greater total sum of crosstalk, it is possible to suppress a total sum of crosstalk of the center core **11***a* according to the relationship. It is possible to balance the crosstalk between the cores **11***a* and **11***b* of the multicore fiber **10** as a whole.

Further, when the distances between the centers of the mutually neighboring cores **11***a* and **11***b* are 30 μm or more, it is possible to reduce crosstalk and, when the distances are 40 μm or more, it is possible to further reduce crosstalk, so that it is possible to secure higher reliability. Furthermore, when the distances between the centers of the cores **11***b* and the outer peripheral surface of the clad **12** are 35 μm or more, loss of a optical signal caused by absorption of light in inner protective layer **13** can be prevented and, consequently, it is possible to secure reliability for communication and, when the distances are 40 μm or more, it is possible to secure higher reliability.

In addition, although an example has been described with the present embodiment where a core is arranged in the center and nine cores are arranged on an outer periphery side, the number of outer periphery side cores is not limited to this, and the number of cores can be adequately changed as long as the number of cores is greater than that of the conventional common multicore fiber in which the cores are provided in the 1-6 arrangement. FIG. **3** illustrates a relationship between the cladding diameter, and distances between the outer periphery side cores and the outer peripheral surface of the clad when the distances between the mutually neighboring cores are 40 μm in a multicore fiber in which a core is arranged in the center and a plurality of cores is arranged around this core at equal intervals.

As illustrated in FIG. **3**, the leftmost line illustrates a relationship between the cladding diameter, and the distances between the centers of the outer periphery side cores **11***b* and the outer peripheral surface of the clad **12** when the cores **11***a* and **11***b* are provided in the 1-6 arrangement. Further, lines right to this line illustrate relationships between the cladding diameter, and the distances between the centers of the outer periphery side cores **11***b* and the outer peripheral surface of the clad **12** when the cores **11***a* and **11***b* are provided in a 1-7 arrangement, a 1-8 arrangement, a 1-9 arrangement, a 1-10 arrangement, a 1-11 arrangement and a 1-12 arrangement in this order.

As described above, the cladding diameter needs to be 230 μm or less from the view point of securing reliability for fracture when the multicore fiber is laid, and the distances between the centers of the cores **11***b* arranged on the outer periphery side and the outer periphery surface of the clad **12** are preferably 35 μm or more and, more preferably, 40 μm or more from the view point of suppressing loss of a optical signal caused by absorption of light in the inner protective layer **13**. In the multicore fiber in which the number of cores is greater than that of the conventional common multicore fiber in which the cores are provided in the 1-6 arrangement, when the core **11***a* is arranged in the center of the clad **12** and a plurality of cores **11** is arranged on the outer periphery side surrounding this core **11***a*, to arrange a greater number of cores while reliability is secured for fracture when the multicore fiber is laid, the number of the outer periphery side cores **11***b* is seven to twelve when the distances between the centers of the cores **11***b* and the outer periphery surface of the clad **12** are 35 μm or less and the number of the outer periphery side cores **11***b* is seven to eleven when the distances between the centers of the cores **11***b* and the outer periphery surface of the clad **12** are 40 μm or less. In addition, when the cores **11***a* and **11***b* are provided in the 1-9 arrangement, the lower limit of the cladding diameter can also be calculated from FIG. **3**.

(Second Embodiment)

Next, referring to FIG. **4**, a second embodiment of the present invention will be described in detail. In addition, components that are identical or similar to those in the first embodiment will be denoted by the same reference numerals as those used in the first embodiment unless particularly described, and will not be described.

FIG. **4** is a view illustrating a structure of a vertical cross section of a multicore fiber in a longitudinal direction according to the second embodiment of the present invention. As illustrated in FIG. **4**, a multicore fiber **20** according to the present embodiment differs from a multicore fiber **10** according to the first embodiment in an arrangement of cores **11***a* and **11***b*. More specifically, three cores **11***a* are arranged at equal intervals surrounding a center C in a cross section of a clad **12**, and nine cores **11***b* are arranged around the center C of the clad **12** surrounding these three cores **11***a*. That is, in the multicore fiber **20** according to the present embodiment, a plurality of cores **11***a* and **11***b* is provided in a 3-9 arrangement.

The multicore fiber **20** according to the present embodiment is an optical fiber which allows propagation of an optical signal similar to the multicore fiber **10** according to the first embodiment, and the mode field diameter of light propagating in the respective cores **11***a* and **11***b* is preferably 9 μm to 13 μm for the same reason as for the multicore fiber **10** according to the first embodiment.

Further, for the same reason as for the multicore fiber **10** according to the first embodiment, distances between centers of the respective cores **11***a* and **11***b* are preferably 30 μm or more and, more preferably, 40 μm or more. Furthermore, for the same reason as for the multicore fiber **10** according to the first embodiment, distances between the centers of the outer periphery side cores **11***b* and the outer periphery side of the clad **12** are also preferably 35 μm or more and, more preferably, 40 μm or more.

In the present embodiment, when the distances between the centers of the mutually neighboring cores **11***a* and **11***b* are 30 μm or more and the distances between the centers of the cores **11***b* arranged on the outer periphery side and the outer peripheral surface of the clad **12** are 35 μm or more as described above, the cladding diameter is 165 μm to 230 μm, and, when the distances between the centers of the mutually neighboring cores **11***a* and **11***b* are 40 μm or more and the distances between the centers of the cores **11***b* arranged on the outer periphery side and the outer peripheral surface of the clad **12** are 40 μm or more, the cladding diameter is 207 μm to 230 μm. The reason why the upper limit of the cladding diameter is 230 μm is the same as the reason why the upper limit of the cladding diameter of the multicore fiber **10** according to the first embodiment is 230 μm.

Twelve cores are arranged according to the arrangement of the cores **11***a* and **11***b* of the multicore fiber **20** according to the present embodiment, so that it is possible to arrange more cores and transmit a greater amount of information than a conventional common multicore fiber in which cores are provided in a 1-6 arrangement.

In addition, when three cores are arranged surrounding the center C of the clad **12** as in the multicore fiber **20** according to the present embodiment, if the number of outer periphery side cores **11***b* surrounding these three cores **11***a* is five or more, it is possible to arrange more cores than the conventional common multicore fiber in which the cores are provided in the 1-6 arrangement. Further, the cladding diameter is 230 μm or less, and therefore the number of the outer periphery side cores **11***b* is twelve or less. Hence, when the three cores are arranged surrounding the center C of the clad **12**, the number of outer periphery side cores is five to twelve. That is, when the three cores are arranged in the center as in the present embodiment, the cores **11***a* and **11***b* are provided in a 3-5 arrangement to a 3-12 arrangement to arrange more cores while reliability is secured for fracture when the multicore fiber is laid.

(Third Embodiment)

Next, referring to FIG. **5**, a third embodiment of the present invention will be described in detail. In addition, components that are identical or similar to those in the first embodiment will be denoted by the same reference numerals as those used in the first embodiment unless particularly described, and will not be described.

FIG. **5** is a view illustrating a structure of a vertical cross section of a multicore fiber in a longitudinal direction according to a third embodiment of the present invention. As illustrated in FIG. **5**, a multicore fiber **30** according to the present embodiment differs from a multicore fiber **10** according to the first embodiment in a core **11***a* arranged in the center, a plurality of cores **11***b* and, in addition, a plurality of cores **11***c* arranged on an outermost periphery side. More specifically, the core **11***a* is arranged in the center in the cross section of a clad **12**, the outermost periphery side six cores **11***c* are arranged at equal intervals surrounding this core **11***a*, and, between connection lines Lc (indicated by broken lines in FIG. **5**) which connect the two mutually neighboring cores **11***c* of the six cores **11***c* and the core **11***a* arranged in the center of the clad **12**, the cores **11***b* are arranged on lines Lv (indicated by dashed lines in FIG. **5**) which are vertical to the connection lines Lc and pass on the core **11***a*. Hence, the six cores **11***b* are arranged. That is, in the multicore fiber **30** according to the present embodiment, a plurality of cores **11***a*, **11***b* and **11***c* is provided in a 1-6-6 arrangement. In addition, in the present embodiment, the respective cores **11***a*, **11***b* and **11***c* are arranged to form a triangular grid.

The multicore fiber **30** according to the present embodiment is an optical fiber which allows propagation of an optical signal similar to the multicore fiber **10** according to the first embodiment, and the mode field diameter of light propagating in the respective cores **11***a*, **11***b* and **11***c* is preferably 9 μm to 13 μm for the same reason as for the multicore fiber **10** according to the first embodiment.

Further, for the same reason as for the multicore fiber **10** according to the first embodiment, distances between centers of the respective cores **11***a*, **11***b* and **11***c* are preferably 30 μm or more and, more preferably, 40 μm or more. Furthermore, for the same reason as for the multicore fiber **10** according to the first embodiment, distances between the centers of the outer periphery side cores **11***c* and the outer periphery side of the clad **12** are also preferably 35 μm or more and, more preferably, 40 μm or more.

FIG. **6** is a view illustrating a relationship between an cladding diameter and distances between outer periphery side cores and an outer peripheral surface of the clad when one core is arranged in the center, six cores are arranged around this core and a plurality of cores is arranged around these six cores at equal intervals, and when the distances between the centers of the mutually neighboring cores are 40 μm. In FIG. **6**, a left side line indicates a relationship between the cladding diameter and the distances between the outer periphery side cores and the outer peripheral surface of the clad in case of a 1-6-6 arrangement similar to the present embodiment, and a right side line indicates a relationship between the cladding diameter and the distances between the outer periphery side cores and the outer peripheral surface of the clad in case of a 1-6-12 arrangement. As illustrated in FIG. **6**, as long as the cores are provided in a 1-6-6 arrangement as in the present embodiment, a line is positioned in an area in which the cladding diameter is 230 μm or less and the distances between the centers of the cores **11***c* arranged on the outer periphery side and the outer peripheral surface of the clad **12** are 40 μm or more. Meanwhile, according to the 1-6-12 arrangement, the line is not positioned in this area, and such an arrangement cannot be adopted.

In the present embodiment, when the distances between the centers of the mutually neighboring cores **11***a*, **11***b* and

11*c* are 30 μm or more and the distances between the centers of the cores **11***b* arranged on the outer periphery side and the outer peripheral surface of the clad **12** are 35 μm or more as described above, the cladding diameter is 174 μm to 230 μm, and, when the distances between the centers of the mutually neighboring cores **11***a* and **11***b* are 40 μm or more and the distances between the centers of the cores **11***b* arranged on the outer periphery side and the outer peripheral surface of the clad **12** are 40 μm or more, the cladding diameter is 219 μm to 230 μm as illustrated in FIG. **6**. In addition, the reason why the upper limit of the cladding diameter is 230 μm is the same as the reason why the upper limit of the cladding diameter of the multicore fiber **10** according to the first embodiment is 230 μm.

Thirteen cores are arranged according to the arrangement of the cores **11***a*, **11***b* and **11***c* of the multicore fiber **30** according to the present embodiment, so that it is possible to arrange more cores and transmit a greater amount of information than a conventional common multicore fiber in which cores are provided in the 1-6 arrangement.

Further, although an example has been described with the present embodiment where the number of cores **11***b* is six, the number of cores **11***b* can be one to six. Hence, the core **11***a* is arranged in the center of the clad **12**, the six cores **11***c* are arranged at equal intervals surrounding this core **11***a* and, between the connection lines Lc connecting the two mutually neighboring cores **11***c* of these six cores **11***c* and the core **11***a* arranged in the center of the clad **12**, at least one core **11***b* may be arranged on the line Lv which is vertical to the connection line Lc and passes on the core **11***a* arranged in the center of the clad **12**. That is, when the core is arranged in the center as in the present embodiment and cores are arranged in three layers as a whole, the cores **11***a*, **11***b* and **11***c* are provided in a 1-1-6 arrangement to a 1-6-6 arrangement to arrange more cores while reliability is secured for fracture when the multicore fiber is laid.

(Fourth Embodiment)

Next, referring to FIG. **7**, a fourth embodiment of the present invention will be described in detail. In addition, components that are identical or similar to those in the first embodiment will be denoted by the same reference numerals as those used in the first embodiment unless particularly described, and will not be described.

FIG. **7** is a view illustrating a state of the multicore fiber according to the fourth embodiment of the present invention. As illustrated in FIG. **7**, a multicore fiber **40** according to the present embodiment differs from a multicore fiber **10** according to the first embodiment in that a plurality of cores **11***a* and **11***b* in the multicore fiber **10** according to the first embodiment is surrounded by inner clad layers **15***a* and **15***b* without gaps and, further, the inner clad layers **15***a* and **15***b* are surrounded by the respective low refractive index layers **16***a* and **16***b*. In the present embodiment, the cores **11***a* and **11***b*, the inner clad layers **15***a* and **15***b* and the low refractive index layers **16***a* and **16***b* form core elements **41***a* and **41***b*.

The outer diameters of the inner clad layers **15***a* and **15***b* are mutually equal, and the outer diameters of the respective low refractive index layers **16***a* and **16***b* are mutually equal. Hence, the thicknesses of the respective inner clad layers **15***a* and **15***b* are mutually equal, and the thicknesses of respective the low refractive index layers **16***a* and **16***b* are mutually equal.

Meanwhile, refractive indices n_5 of the respective inner clad layers **15***a* and **15***b* and the refractive index n_2 of the clad **12** are lower than the refractive indices n_1 of the respective cores **11***a* and **11***b*, and the refractive indices n_6 of the low refractive index layers **16***a* and **16***b* are lower than the refractive indices n_5 of the inner clad layers **15***a* and **15***b* and the refractive index n_2 of the clad **12**. In other words, the respective refractive indices n_1, n_2, n_5 and n_6 all satisfy

$$n_1>n_5>n_6,$$

$$n_1>n_2 \text{ and}$$

$$n_6<n_2.$$

Further, in the present embodiment, the refractive indices n_5 of the inner clad layers **15***a* and **15***b* and the refractive index n_2 of the clad **12** are mutually equal. That is, $n_5=n_2$ is true.

From the view point of the refractive indices of the respective core elements **41***a* and **41***b*, the low refractive index layers **16***a* and **16***b* have low shapes like trenches in the respective core elements **41***a* and **41***b*, and the core elements **41***a* and **41***b* adopt the trench structures. In addition, in the present embodiment, the refractive indices of the respective low refractive index layers **16***a* and **16***b* are uniform in the respective low refractive index layers **16***a* and **16***b*, and the refractive indices of the respective low refractive index layers **16***a* and **16***b* and the average refractive index means the same.

In addition, the inner clad layers **15***a* and **15***b* have the refractive indices equal to the clad **12** as described above, and therefore is formed using, for example, the same material as that of the clad **12**. Further, the low refractive index layers **16***a* and **16***b* are made of silica glass doped with a dopant which decreases the refractive indices. Such a dopant is, for example, fluorine.

In the respective core elements **41***a* and **41***b* of this multicore fiber **40**, the refractive indices n_6 of the low refractive index layers **16***a* and **16***b* are lower than the refractive indices n_5 of the inner clad layers **15***a* and **15***b* and the refractive index n_2 of the clad **12**, so that an effect of light confinement in the cores **11***a* and **11***b* increases and light hardly leaks from the cores **11***a* and **11***b*. Consequently, it is possible to prevent light propagating in the cores **11***a* and **11***b* from leaking from the core elements **41***a* and **41***b*. Further, the low refractive index layers **16***a* and **16***b* and the clad **12** having the low refractive indices serve as barriers, so that it is possible to prevent crosstalk between the cores **11***a* and **11***b* in the mutually neighboring core elements.

Hereinafter, an example of the property according to the present embodiment will be described. In this multicore fiber **40**, the cladding diameter is 204.4 μm, the distances between the centers of the center core **11***a* and outer periphery side cores **11***b* are 59.2 μm, the distances between the outer periphery side cores **11***b* are 40.5 μm, the distances between the centers of the outer periphery side cores **11***b* and the outer peripheral surface of the clad **12** are 43 μm, the thicknesses of the inner clad layers **15***a* and **15***b* are 6.0 μm respectively, the thicknesses of the low refractive index layers **16***a* and **16***b* are 4.3 μm, the relative refractive index difference of the center core is 0.23% and the relative refractive index differences of the low refractive index layers are −0.65%.

In this multicore fiber **40**, when an optical signal having a wavelength in a 1.55 μm band propagates in the cores **11***a* and **11***b*, an effective cross-sectional area Aeff of the center core **11***a* is 116.04 μm^2, a cutoff wavelength is 1.25 μm, the effective cross-sectional areas Aeff of the outer periphery side cores **11***b* are 118.2 μm^2 to 125.2 μm^2, and cutoff wavelengths are 1.28 μm to 1.39 μm. Further, crosstalk between the outer periphery side cores **11***b* when a measurement length is 3.96 km is −38.6 dB to −41.6 dB, and crosstalk between the center core **11**a and the outer periphery side cores **11**b is −71.7 to −75.2 dB.

(Fifth Embodiment)

Next, referring to FIG. **8**, a fifth embodiment of the present invention will be described in detail. In addition, components that are identical or similar to those in the fourth embodiment will be denoted by the same reference numerals as those used in the fourth embodiment unless particularly described, and will not be described.

FIG. **8** is a view illustrating a structure of a vertical cross section of a multicore fiber in a longitudinal direction according to the fifth embodiment of the present invention. As illustrated in FIG. **8**, a multicore fiber **50** according to the present embodiment differs from a multicore fiber **40** according to the fourth embodiment in that, instead of respective core elements **41**a and **41**b according to the fourth embodiment, core elements **51**a and **51**b arranged at the same spots as those of the respective core elements **41**a and **41**b are arranged. More specifically, in the respective core elements **51**a and **51**b, low refractive index layers **17**a and **17**b are arranged instead of low refractive index layers **16**a and **16**b according to the fourth embodiment.

In the respective low refractive index layers **17**a and **17**b, a plurality of low refractive index portions **18** which have lower refractive indices than those of the clad **12** and the inner clad layers **15**a and **15**b are formed surrounding the inner clad layers **15**a and **15**b. In the present embodiment, a plurality of circular holes is formed in the low refractive index layers **17**a and **17**b, and these holes are the low refractive index portions **18**. Hence, the shape in the cross section of the low refractive index portion **18** is circular. In the present embodiment, the cores **11**a and **11**b, the inner clad layers **15**a and **15**b and the low refractive index layers **17**a and **17**b form core elements **51**a and **51**b.

Further, in the present embodiment, an area other than the low refractive index portions **18** in the respective low refractive index layer **17**a and **17**b is made of the same material as those of the clad **12** and the inner clad layers **15**a and **15**b. Furthermore, the low refractive index portions **18** are holes, and the refractive indices of the low refractive index portions **18** are 1 and are lower than the refractive indices of the inner clad layers **15**a and **15**b and the clad **12** and the average refractive index of the low refractive index layers **17**a and **17**b is lower than those of the inner clad layers **15**a and **15**b and the clad **12**.

In the multicore fiber **50** according to the present embodiment, the low refractive index portions **18** which have low refractive indices are not continuously annularly formed surrounding the respective cores **11**a and **11**b, so that it is possible to allow a higher mode to adequately escape from the respective cores **11**a and **11**b. Consequently, it is possible to prevent the cutoff wavelengths of the cores **11**a and **11**b from becoming long.

Further, the low refractive index portions **18** are holes, so that it is possible to make the refractive index of the low refractive index layers **17**a and **17**b lower, and further reduce crosstalk between the respective cores **11**a and **11**b while preventing the respective cores **11**a and **11**b from intensifying confinement of a higher mode.

In addition, although, in the present embodiment, the low refractive index portions **18** are formed as holes and, consequently, it is possible to make the refractive indices of the low refractive index portions **18** smaller, the low refractive index portions **18** are not limited to holes, and the material is not limited in particular as long as the material has a lower refractive index than those of the inner clad layers **15**a and **15**b and the clad **12**. For example, the low refractive index portions **18** may be formed using silica doped with a dopant such as fluorine which decreases the refractive index. Even in this case, it is possible to reduce the number of silica doped with fluorine which is costly in the multicore fiber **50** according to the present embodiment, and manufacture the multicore fibers **50** at low cost.

(Sixth Embodiment)

Next, referring to FIG. **9**, a sixth embodiment of the invention will be described in detail. In addition, components that are identical or similar to those in the first embodiment will be denoted by the same reference numerals as those used in the first embodiment unless particularly described, and will not be described.

FIG. **9** is a view illustrating a structure of a vertical cross section of a multicore fiber in a longitudinal direction according to the six embodiment of the present invention. As illustrated in FIG. **6**, a multicore fiber **60** according to the present embodiment differs from a multicore fiber **10** according to the first embodiment in the number and an arrangement of cores **11**b. More specifically, a core **11**a arranged in a center of a clad **12** is surrounded by eight cores **11**b, and these eight cores **11**b are arranged at equal intervals to form a square as a whole.

The multicore fiber **60** according to the present embodiment is an optical fiber which allows propagation of an optical signal similar to the multicore fiber **10** according to the first embodiment, and the mode field diameter of light propagating in the cores **11**a and **11**b is preferably 9 μm to 13 μm for the same reason as for the multicore fiber **10** according to the first embodiment.

Further, for the same reason as for the multicore fiber **10** according to the first embodiment, distances between centers of the cores **11**a and **11**b are preferably 30 μm or more and, more preferably, 40 μm or more. Furthermore, for the same reason as for the multicore fiber **10** according to the first embodiment, distances between the centers of the outer periphery side cores **11**b and the outer periphery side of the clad **12** are also preferably 35 μm or more and, more preferably, 40 μm or more.

In the present embodiment, when the distances between the centers of the mutually neighboring cores **11**a and **11**b are 30 μm or more and the distances between the centers of the cores **11**b arranged on the outer periphery side and the outer peripheral surface of the clad **12** are 35 μm or more as described above, the cladding diameter is 155 μm to 230 μm, and, when the distances between the centers of the mutually neighboring cores **11**a and **11**b are 40 μm or more and the distances between the centers of the cores **11**b arranged on the outer periphery side and the outer peripheral surface of the clad **12** are 40 μm or more, the cladding diameter is 194 μm to 230 μm. The reason why the upper limit of the cladding diameter is 230 μm is the same as the reason why the upper limit of the cladding diameter of the multicore fiber **10** according to the first embodiment is 230 μm.

Ten cores are arranged according to the arrangement of the cores **11**a and **11**b of the multicore fiber **60** according to the present embodiment, so that it is possible to arrange more cores and transmit a greater amount of information than a conventional common multicore fiber in which cores are provided in the 1-6 arrangement.

(Seventh Embodiment)

Next, referring to FIG. **10**, a seventh embodiment of the present invention will be described in detail. In addition, components that are identical or similar to those in the first embodiment will be denoted by the same reference numerals as those used in the first embodiment unless particularly described, and will not be described.

FIG. **10** is a view illustrating a structure of a vertical cross section of a multicore fiber in a longitudinal direction according to the seventh embodiment of the present invention. As illustrated in FIG. **10**, a multicore fiber **70** according to the present embodiment differs from a multicore fiber **10** according to the first embodiment in the number and an arrangement of cores **11***a* and **11***b*. More specifically, the number of cores **11***a* is four, and the cores **11***a* are arranged at equal distances from a center C of a clad **12** and at equal intervals. Further, the number of cores **11***b* which surround these cores **11***a* is eight, and the cores **11***b* are arranged one by one respectively, on extended lines Le (indicated by broken lines in FIG. **10**) connecting two mutually neighboring cores **11***a* of the four cores **11***a* and are arranged such that a distance to the center of the closest core **11** of the four cores **11***a* is equal to the distances between the centers of the two mutually neighboring cores **11***a* of the four cores **11***a*. That is, when the distance between the centers of the two mutually neighboring cores **11***a* is d, the distance between the centers of the specific core **11***b* and the core **11***a* closest to this specific core **11***b* is also d.

The multicore fiber **70** according to the present embodiment is an optical fiber which allows propagation of an optical signal similar to the multicore fiber **10** according to the first embodiment, and the mode field diameter of light propagating in the cores **11***a* and **11***b* is preferably 9 μm to 13 μm for the same reason as for the multicore fiber **10** according to the first embodiment.

Further, for the same reason as for the multicore fiber **10** according to the first embodiment, distances between centers of the respective cores **11***a* and **11***b* are preferably 30 μm or more and, more preferably, 40 μm or more. Furthermore, for the same reason as for the multicore fiber **10** according to the first embodiment, distances between the centers of the outer periphery side cores **11***b* and the outer periphery side of the clad **12** are also preferably 35 μm or more and, more preferably, 40 μm or more.

In the present embodiment, when the distances between the centers of the mutually neighboring cores **11***a* and **11***b* are 30 μm or more and the distances between the centers of the cores **11***b* arranged on the outer periphery side and the outer peripheral surface of the clad **12** are 35 μm or more as described above, the cladding diameter is 165 μm to 230 μm, and, when the distances between the centers of the mutually neighboring cores **11***a* and **11***b* are 40 μm or more and the distances between the centers of the cores **11***b* arranged on the outer periphery side and the outer peripheral surface of the clad **12** are 40 μm or more, the cladding diameter is 207 μm to 230 μm. The reason why the upper limit of the cladding diameter is 230 μm is the same as the reason why the upper limit of the cladding diameter of the multicore fiber **10** according to the first embodiment is 230 μm.

Ten cores are arranged according to the arrangement of the cores **11***a* and **11***b* of the multicore fiber **70** according to the present embodiment, so that it is possible to arrange more cores and transmit a greater amount of information than a conventional common multicore fiber in which cores are provided in the 1-6 arrangement.

Although the present invention has been described above by reference to the first to seventh embodiments as examples, the present invention is not limited thereto.

For example, in the first embodiment to the third embodiment, the sixth embodiment and the seventh embodiment, these cores **11***a* and **11***b* may be surrounded by inner clad layers and low refractive index layers as in the fourth embodiment and the fifth embodiment.

Industrial Applicability

As describe above, the present invention provides a multicore fiber for communication in which more cores can be arranged under conditions that the multicore fiber for communication can be laid while reliability is secured, and is useful for communication optical fibers for short distance transmission disposed in households and communication optical fibers for long distance transmission such as undersea cables.

REFERENCE SIGNS LIST

10, **20**, **30**, **40**, **50**, **60**, **70** . . . Multicore fiber
11*a*, **11***b*, **11***c* . . . Core
12 . . . Clad
13 . . . Inner protective layer
14 . . . Outer protective layer
15*a*, **15***b* . . . Inner clad layer
16*a*, **16***b*, **17***a*, **17***b* . . . Low refractive index layer
18 . . . Low refractive index portion
41*a*, **41***b*, **51***a*, **51***b* . . . Core element

The invention claimed is:

1. A multicore fiber for communication comprising:
a clad;
a first core which is arranged in a center of the clad; and
eight second cores which surround the first core and are arranged at equal intervals such that the first core and the second cores are arranged in an array of 3×3 matrix,
wherein the clad has a diameter of 230 μm or less and 155 μm or more,
a mode field diameter of light propagating in each of the first core and the second cores is 9 μm to 13 μm so as to prevent loss of light from increasing due to a non-linear optical effect because of concentration of light on the cores, and to prevent loss of light from increasing due to an increase of amount of light leaking to an outside from the cores; and
a distance between centers of the cores which are mutually neighboring is 30 μm or more to prevent crosstalk between the mutually neighboring cores, and a distance between the center of the respective second cores and an outer peripheral surface of the clad is 35 μm or more.

2. The multicore fiber for communication according to claim **1**, wherein the clad contains therein:
inner clad layers each surrounding corresponding one of the first core and the second cores and having a lower refractive index than the refractive index of the corresponding one of the first core and the second cores; and
low refractive index layers each surrounding corresponding one of the inner clad layers and having a lower average refractive index than the refractive index of the corresponding one of the inner clad layers and the refractive index of the clad.

3. The multicore fiber for communication according to claim **2**, wherein each of the low refractive index layers is made of a material having a lower refractive index than the refractive index of the clad and the refractive index of the corresponding one of the inner clad layers.

4. The multicore fiber for communication according to claim **2**, wherein, in each of the low refractive index layers, a plurality of low refractive index portions which have lower refractive indices than the refractive index of the clad and the refractive index of the corresponding one of the inner clad layers is formed surrounding the corresponding one of the inner clad layers.

5. The for communication multicore fiber for communication according to claim **4**, wherein the low refractive index portions are hole.

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